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(54) Title: PLANAR MICROPUMP WITH INTEGRATED MICROVALVES

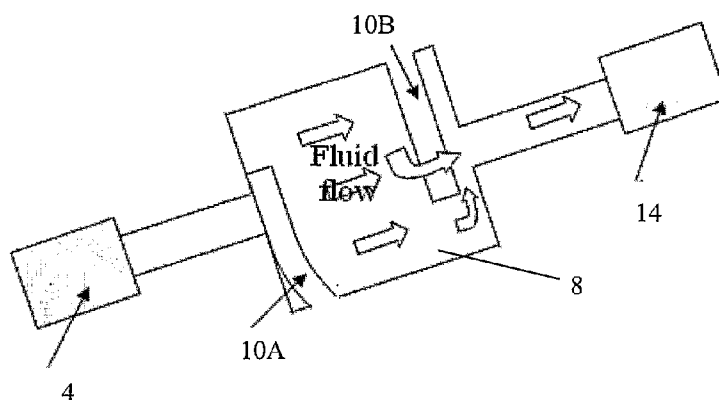


FIG. 2-B

(57) Abstract: The present invention relates generally to a planar micropump (2) with integrated microvalves (10) which is capable of efficiently controlling fluid flow in a miniaturised chemical analyser system to maintain isolation of chemical fluids until the appropriate time for mixing.

PLANAR MICROPUMP WITH INTEGRATED MICROVALVES

1. TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to a planar micropump with integrated microvalves which is capable of efficiently controlling fluid flow in a miniaturised chemical analyser system to maintain isolation of chemical fluids until the appropriate time for mixing.

2. BACKGROUND OF THE INVENTION

Microvalves that are required to control the flow in and out of the pump are a vital part of the micropump. This is because when fluids are not isolated but allowed to mix at an inappropriate time the result of the chemical analysis will be affected. The trend today is to miniaturised microfluidic systems. A miniaturised microfluidic system requires the means of introducing sample, reagent and buffer solutions while maintaining isolation between chemicals until appropriate times. This necessitates the fabrication of microchannels, microvalves and micropumps.

A typical stack micromechanical pump with a set of inlet-outlet valves, a pressure chamber, flexible diaphragm and an actuator, requires complex alignment and processing in multiple substrate surfaces which is a barrier to further miniaturisation of the overall system.

Until today, typical planar type micropumps have been fabricated with passive nozzle-diffuser type valves which have an issue of large leakage flow or a series of active pump-valve system which is typically large in dimensions and thus does not facilitate miniaturisation.

It would hence be extremely advantageous if the above shortcoming is overcome by having a novel planar type micropump with integrated active valves capable of facilitating miniaturisation. The valves are fabricated in-plane with the channels on the same substrate surface; hence it eases fabrication and alignment complexities. With the integration of valves the planar type pump is capable of eliminating fluid leakage or back flow issue that is prevalent in conventional models.

3. SUMMARY OF THE INVENTION

Accordingly, it is the primary aim of the present invention to provide a planar micropump with integrated microvalves wherein the whole device or system is integrated and fabricated in-plane on a single substrate (or the same wafer) thereby allowing total analysis, (sample preparation, pre-treatment, analytical reactions, detection, and results) to be combined in a single device or chip.

Yet a further object of the present invention is to provide a planar micropump with integrated microvalves which eases fabrication and alignment complexities as the microvalves and microchannels are on the same substrate surface.

It is yet another object of the present invention to provide a planar micropump with integrated microvalves which is capable of eliminating fluid leakage and back-flow problems.

It is yet another object of the present invention to provide a planar micropump with integrated microvalves which saves energy as the micropump and micro valves can be driven electrostatically requiring minimal actuation voltage as low as below 5 volts (V).

It is yet another object of the present invention to provide a planar micropump with integrated microvalves which facilitates portability of the overall system thereby allowing analysis to be performed close to the sample source.

5 Yet a further object of the present invention is to provide a planar micropump with integrated microvalves which encourages or facilitates miniaturization to greatly reduce the volume of chemicals involved, typically to the microlitre and nanolitre ranges, promotes low chemical consumption and affords a speedy response time.

10 It is a further object of the present invention to provide a planar micropump with integrated microvalves which is applicable for microfluidic applications typically in the areas of drug delivery, agriculture, environmental monitoring and micro-analyser systems.

15 Yet another object of the present invention is to provide a planar micropump with integrated microvalves having the ability to perform multiple different assays leading to reduced cost per assay.

Other and further objects of the invention will become apparent with an understanding of the following detailed description of the invention or upon employment of the invention in practice.

According to a preferred embodiment of the present invention there is provided,

A micropump (2) to control fluid flow comprising,

at least a pump chamber (8);

5 at least a fluid inlet port (4);

at least a fluid inlet microchannel (6) to direct flow of fluids;

at least a fluid outlet port (14);

characterised in that

said pump chamber (8) is integrated with active microvalves (10).

10 4. BRIEF DESCRIPTION OF THE DRAWINGS

Other aspect of the present invention and their advantages will be discerned after studying the Detailed Description in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic diagram of a micropump to control fluid flow for use chemical analysis integrated with microvalves.

FIGS. 2-A shows a sectional view of the micropump illustrating the deflection of the diaphragm of the pump in relation to the microvalves when in operation mode.

FIG. 2-B shows fluid flow in the pump chamber during deflection of the diaphragm shown in FIG. 2-A.

FIG. 3 is a view of one embodiment of the micropump with the active microvalve being provided to electrostatic parallel electrode actuators.

FIG. 4 is a view of another embodiment of the micropump with the active microvalve being electrostatic curved electrode actuators.

5. DETAILED DESCRIPTION OF THE DRAWINGS

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention.

However, it will be understood by those of ordinary skill in the art that the invention may be practised without these specific details. In other

instances, well known methods, procedures and/or components have not been described in detail so as not to obscure the invention.

The invention will be more clearly understood from the following description of the embodiments thereof, given by way of example only with reference to the accompanying drawings, which are not drawn to scale.

Referring now to FIGS. 1, 2-A and 2-B, there are respectively shown a micropump (2) to control fluid flow for use in chemical analysis provided with integrated microvalves (10), a sectional view of the micropump illustrating the diaphragm of the pump in relation to the microvalves when in operation mode and fluid flow in the pump chamber during deflection of the diaphragm shown in FIG. 2-A. The said micropump (2) illustrated in FIG. 1 comprises at least a fluid inlet port (4), at least a fluid inlet microchannel (6), at least a pump chamber (8) integrated with at least an active microvalve (10), at least a fluid exit microchannel (12) and an fluid outlet port (14). A generalised chemical analysis procedure requires the flow of liquid sample and chemical reagents to one or more testing points. Subsequent flushing with buffer solutions or treatment with additional reagents may be required. The reaction occurring at the test unit can be quantified by measuring the changes in mass, chemical

properties or colour. A miniaturised system thus requires a means of inducing sample, reagent and buffer as well as maintaining isolation between the chemicals until appropriate times. This necessitates the fabrication of microchannels, microvalves and micropumps. Fluid such as fluid samples buffer or chemical reagents for chemical analysis procedure are stored in the fluid inlet port (4). The passage of fluid that is directed through the said fluid inlet microchannel (6) to the pump chamber (8) where the active valves or microvalves (10) are integrated therein the pump chamber (8). The microvalves (10) are fabricated on the same substrate (22) surface as the fluid inlet microchannels (6) and this greatly eases fabrication and alignment complexities as both are on the same substrate surface and not set in different planes. The normally open microvalves (10) are controlled by electro-thermal or electro-static actuation requiring minimal actuation voltage as low as below 5 volts (V) thereby saving energy.

When the micropump (2) operates, the pump diaphragm (11) as illustrated in FIG. 2-A will be actuated to allow fluid from the fluid inlet port (4) to be drawn into the fluid inlet microchannel (6) connected to the pump chamber (8) and then into the pump chamber (8). The pump diaphragm (11) can typically be driven by electrostatic, thermopneumatic, piezoelectric, bimetallic and shape-memory type actuation.

The working principle of the pump can be described as a process cycle. When the diaphragm (11) deflects downwards, the inlet microvalve (10A) is actuated to close and outlet microvalve (10B) is actuated to open causing fluid to exit from the pump chamber (8) through the outlet microvalve (10B) as shown by the arrows illustrated in FIGS. 2-A and 2-B while the inlet microvalve (10A) blocks the back-flow of fluid into the fluid inlet microchannel (6). When the diaphragm (11) relaxes to its initial or original position the opposite will occur that is the outlet microvalve (10B) is actuated to close and inlet microvalve (10A) is actuated to open causing fluid to flow through the inlet microvalve (10A) filling up the pump chamber (8) with fluid while at the same time the outlet microvalve (10B) will block the back-flow from the fluid outlet microchannel (12) into the pump chamber (8). The simultaneous closing and opening of the outlet microvalve (10B) and inlet microvalve (10A) respectively and vice versa ensures isolation of fluids so that different fluids do not mix when not required to.

The micropump (2) is designed to ease fabrication complexities where only a single substrate is required and is capable of further miniaturisation for nanofluidic applications. It is capable of limiting fluid leakage or back flow issues as when inlet microvalve (10A) is opened the

outlet microvalve (10B) is simultaneously closed and vice versa thus not giving an opportunity for such instances to occur.

Electrostatic actuation is very attractive for micro-electro-mechanical systems (MEMs) because of good scaling properties to small dimensions, high energy densities and its relative ease of fabrication. Electrostatic actuation is utilized in this invention to control the opening and closing of microvalves. One embodiment of the micropump (2) has the said active microvalve (10) being actuated using electrostatic parallel electrode actuators (16A) wherein the said electrode (16A) is parallel to the microvalve (10) and therefore has a consistent gap distance (20A) between the microvalve (10) and the said parallel electrode (16A) as illustrated in FIG. 3 and another embodiment of the micropump (2) has the said active microvalve (10) being actuated using electrostatic curved electrode actuators (16B) wherein the said electrode (16B) is curved in relation to the microvalve (10) and therefore has a gap distance (20B) that gradually increases towards the point of maximum displacement as illustrated in FIG. 4. By employing these electrostatic electrode actuators large displacement and large forces can be realized and hence able to save energy thus the microvalves (10) can be operated at less than 5V.

The fluid that exits from the pump chamber (8) into the fluid exit microchannel (12) will be channelled into the fluid outlet port (14) for collection.

The micropump (2) and microvalve (10) can be fabricated on various types of substrates and materials, namely, silicon, polysilicon, silicon on insulator, glass, plastic, metal or polymer by surface machining or bulk machining or a combination of both techniques.

Although only one inlet microvalve (10A) and only one outlet microvalve (10B) have been described and illustrated it is to be understood that the number of inlet microvalves and outlet microvalves may be more than one, as what is advantageous is the effective isolation of fluids until an appropriate time where mixing is required.

The overall invention is designed to ease fabrication complexities where only a single substrate is required and is capable of further miniaturisation for nanofluidic applications. The planar design wherein the said micropump (2) with integrated active microvalves (10) are fabricated utilising CMOS-compatible surface micromachining fabrication process flow which presents the possibility of mass production, integration with other electronics and cost reductions. The complete integrated form of such systems is more commonly known as laboratory-

on-a-chip (LOC) or a micro-total-analysis-system (μ TAS) wherein the whole device or system is integrated and fabricated in-plane on a single substrate (or the same wafer) thereby allowing total analysis (sample preparation, pre-treatment, analytical reactions, detection, and results) to be combined in a single device or chip. It can be extended into the field of environmental monitoring applications in the area of sensors for detection of air and water pollution.

While the preferred embodiment of the present invention and its advantages has been disclosed in the above Detailed Description, the invention is not limited thereto but only by the spirit and scope of the appended claim.

WHAT IS CLAIMED IS:

1. A micropump (2) to control fluid flow comprising,

at least a pump chamber (8);

at least a fluid inlet port (4);

- 5 at least a fluid inlet microchannel (6) to direct flow of fluids;

at least a fluid outlet port (14);

characterised in that

said pump chamber (8) is integrated with active microvalves (10).

2. A micropump (2) to control fluid flow as in Claim 1 further

10 characterised in that all devices or system are fabricated in-plane on a

single substrate.

3. A micropump (2) to control fluid flow as in Claim 2 wherein the

substrate is made of silicon, polysilicon, silicon on insulator, glass,
plastic, metal or polymer by surface machining or bulk machining or a

15 combination of both techniques.

4. A micropump (2) to control fluid flow as in Claim 1, 2 or 3 wherein the said micropump (2) with integrated active microvalves (10) are fabricated using CMOS-compatible surface micromachining.
5. A micropump (2) to control fluid flow as in Claim 1 or 2 wherein the microvalve (10) is actuated by electrostatic parallel electrode actuators.
6. A micropump (2) to control fluid flow as in Claim 1 or 2 wherein the microvalve (10) is actuated by electrostatic curved electrode actuators.
7. A micropump (2) to control fluid flow as in Claim 1 or 2 for use in chemical analysis.
10. 8. A micropump (2) to control fluid flow as in Claim 1 or 2 which is applicable to the field of environmental monitoring applications in the area of sensors for detection of air and water pollution.
9. A method of controlling the flow of fluid in a micropump (2) comprising steps of,
15. deflecting the pump diaphragm downwards,

actuating the inlet microvalve (10A) to close while simultaneously actuating the outlet microvalve (10B) to open using electrostatic electrodes;

5 causing fluid to exit from the pump chamber (8) through the outlet microvalve (10B) while the inlet microvalve blocks the back-flow of fluid into the fluid inlet microchannel (6);

relaxing the pump diaphragm to its initial or original position;

actuating the outlet microvalve (10B) to close while simultaneously actuating the inlet microvalve (10A) to open using electrostatic electrodes;

10 causing fluid to flow through the inlet microvalve (10A) filling up the pump chamber (8) while the closed outlet microvalve (10B) blocks the back-flow of fluid from the outlet microchannel (12) into the pump chamber (8);

collecting fluid in the fluid outlet port (14).

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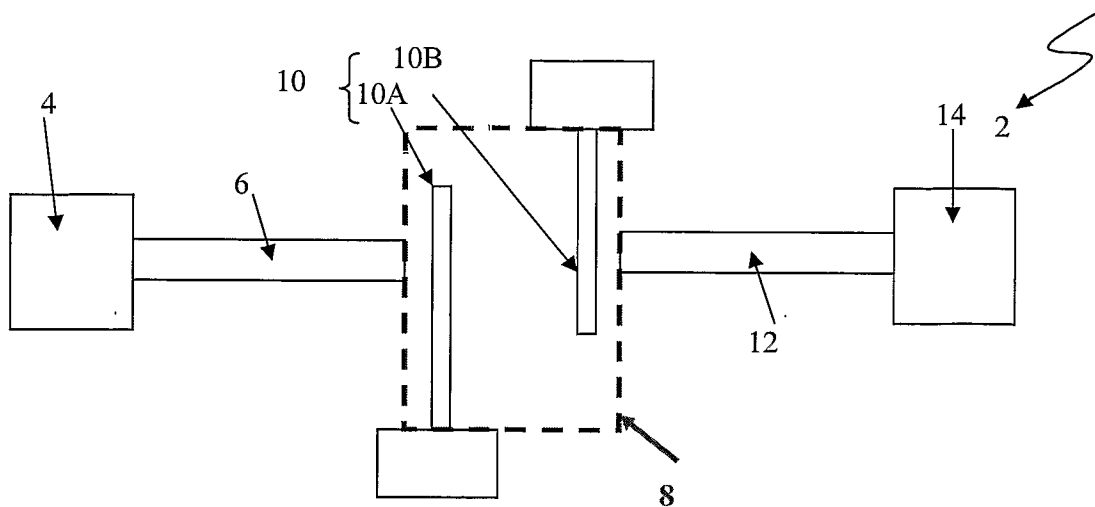


FIG. 1

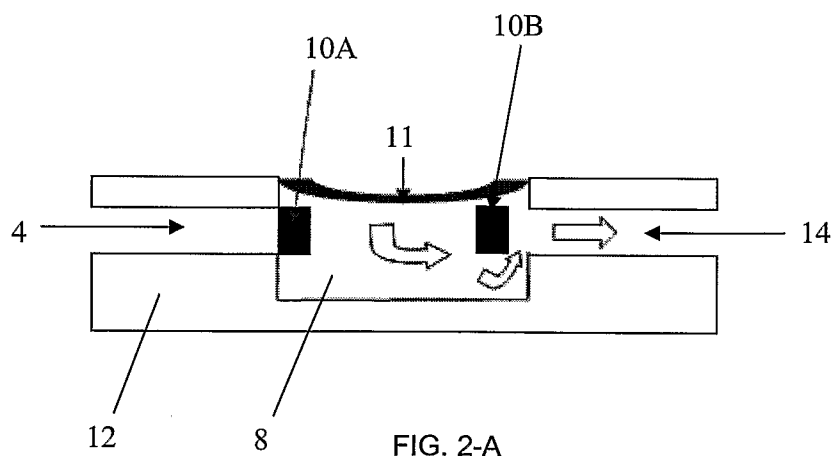


FIG. 2-A

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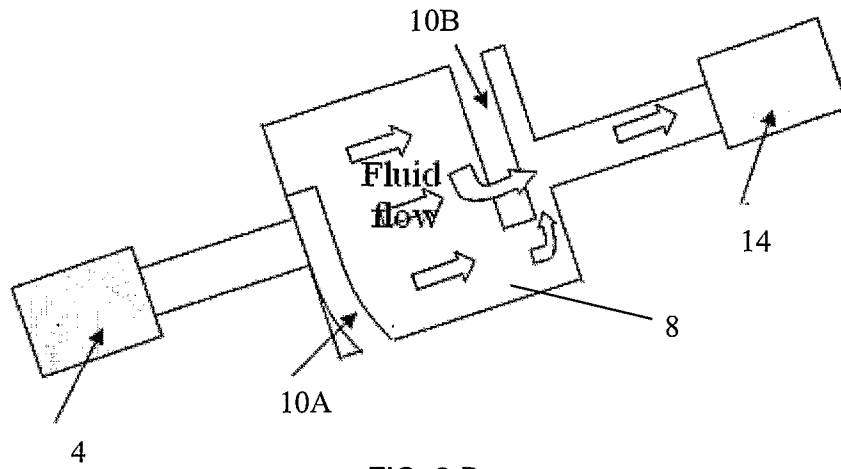


FIG. 2-B

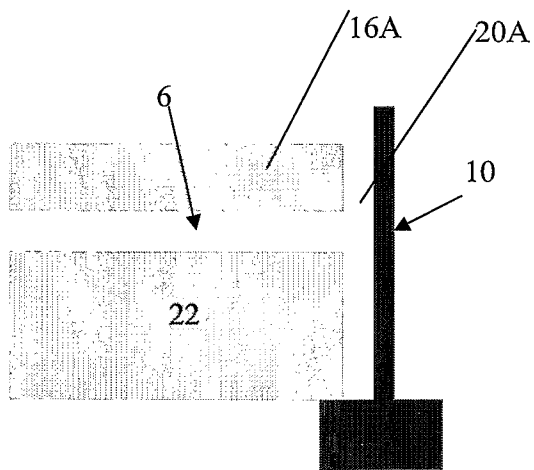


FIG. 3

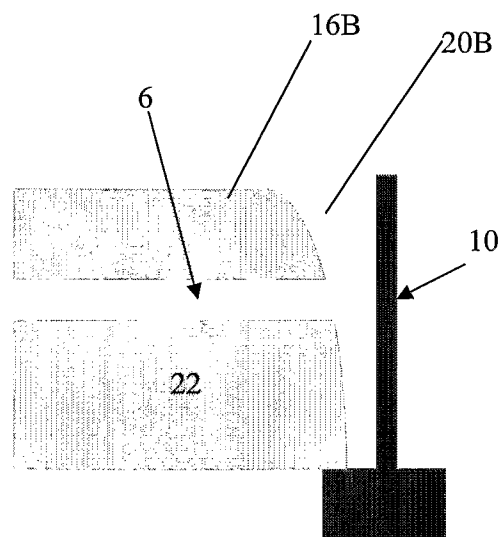


FIG. 4

A. CLASSIFICATION OF SUBJECT MATTER*G01N 35/08(2006.01)i, G01N 33/18(2006.01)i, G01N 1/38(2006.01)i*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 8: G01N 35/08; B82Y 35/00; B81B 7/02; C12P 19/34; B81B 3/00; B01D 17/06; C12M 1/34

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: microfluidic, micropump, microvalve, chamber, substrate, silicon, CMOS, LOC, and actuator

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009-0317302 A1 (MCAVOY, GREGORY JOHN et al.) 24 December 2009 See paragraphs 391-420,367; claims 1-15; figs. 6-13.	1-9
A	US 2004-0209354 A1 (MATHIES, RICHARD A. et al.) 21 October 2004 See paragraphs 48-50; claim 1; fig. 3.	1-9
A	KR 10-2010-0028526 A (MICROCHIP BIOTECHNOLOGIES, INC.) 12 March 2010 See paragraphs 148-153; claims 1,14,24; figs. 23-25.	1-9
A	US 2009-0253181 A1 (VANGBO, MATTHIAS et al.) 08 October 2009 See paragraphs 3-17; claim 1; figs. 1-2.	1-9



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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